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THE COMPENSATED PULSED ALTERNATOR PROGRAM - A REVIEW

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Summary

Since 1978 the Center for Electromechanics at the University of Texas at Austin (CEM-UT) has pursued a program to develop a class of electromechanical devices, rated for pulsed duty, which are capable of delivering one to ten megajoules to a load in less than one millisecond.[1] Initial work has centered on driving xenon flashlamps (500 μsec) and charging high energy density energy transfer capacitors (<100 μsec). A 200 kJ (3.5 MJ stored) engineering prototype compensated pulsed alternator and a smaller scale (100 kJ stored) active rotary flux compressor have been designed, fabricated, and tested. Experimental results have been factored into machine design algorithms and circuit simulation codes to form conceptual designs of full scale pulse generators. Engineering problems remain to be solved, including the design of high packing factor air gap windings, reliable electrical insulation systems having mechanical shear strength (in excess of 27 MPa), and inexpensive laminated steel rotor and stator structures. Proposed solutions to these problems are presented, and near term and long range program goals are summarized for both resistive and capacitive loads.

Introduction

The Center for Electromechanics at the University of Texas at Austin (CEM-UT) has participated in inertial energy storage research and development since its conception as the Energy Storage Group in 1972. The original emphasis of CEM-UT research was concentrated on inertial energy storage systems utilizing homopolar generator conversion. The work focused on the development of pulsed power supplies for driving tokamak toroidal and poloidal field coils and theta pinch compression coils. Homopolar generators, utilizing normal or superconducting field magnets, are well suited to these tasks, which require discharge times ranging from 30 milliseconds to several seconds.

As size, cost and complexity pose limits to conventional capacitive energy storage, another storage system, having higher energy storage density, will be required. While rotating electrical machines have the inherent advantage of inexpensive inertial energy storage, the volumetric power density is considerably lower than capacitive systems. In an effort directed toward increasing the peak power rating of electromechanical systems, CEM-UT proposed the compensated pulsed alternator approach in January, 1978.

The basic idea behind the compulsator concept is to combine alternator action with rotary flux compression to produce current pulses of large magnitude (100 kA to 1 MA) at moderate voltage levels (10-20 kV) from a potentially rep-rateable system--most likely in a burst mode. The approach is based on the following principles:

1. Connect compensating winding in series with armature winding through slip rings. Compensating winding is series-aiding at initiation of pulse and is series-opposing at peak current.
2. Wind armature and compensating coils on smooth cylindrical structures in the air gap.
3. Increase pole span to 85 percent of pole pitch
4. Increase average open circuit flux density to 2.0 T
5. Minimize insulation thickness and mechanical clearances
6. Increase surface velocity to 150 m/sec
7. Increase apparent modulus of lamination stack to increase allowable l/D of rotor

A simplified cross-sectional diagram of a compensated, pulsed alternator is shown in Figure 1.

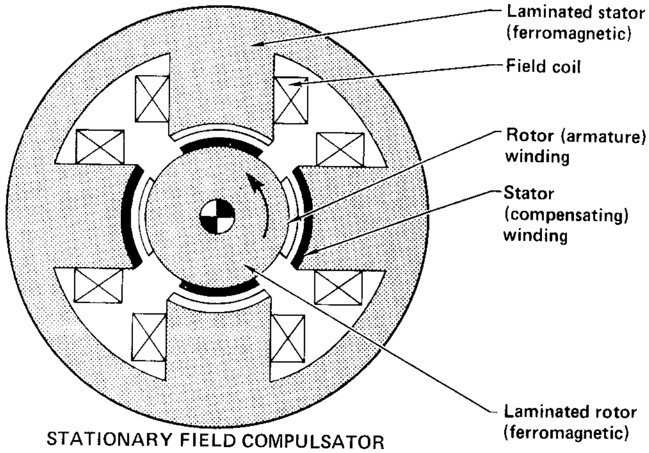

Figure 1

In the drum configuration shown above the armature circuit conductors are made radially thin and tangentially wide (span 80 percent of pole pitch) to minimize inductance. The windings are not imbedded in slots to avoid slot leakage inductance and to maximize the average radial flux density. The effective inductance of the armature circuit varies with the angular position of the rotor due to the variable mutual coupling between the armature and compensating windings. This gives rise to compression of the armature flux.

Since the conductors are not imbedded in slots, the windings are exposed to the applied radial magnetic field and must be finely stranded to hold the open circuit eddy current losses to an acceptable level. Rectangular Litz wire conductors are wound in parallel (e.g., ten in hand) to form a conductor. The Litz wires are wound in a serpentine fashion starting at one end of the rotor (output terminal) and ending at the other end of the rotor (jumper between armature and compensating windings).

With an air gap winding configuration, the full energy conversion forces are applied directly to the conductors. Since the moment of inertia of the conductors is negligible compared to the total inertia of the rotor, the electromechanical discharge forces must be transmitted to the rotor (or stator) in mechanical shear of the electrical insulation system. Therefore, the interlaminar shear strength of the insulation and the bond strength between laminated sheet steel and insulation must be pushed to state of the art engineering limits to maximize surface power density.

It is necessary to minimize insulation thickness

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not only to reduce the minimum inductance, but to increase the maximum inductance and thereby maximize the flux compression ratio. Any improvements in the dielectric and/or mechanical strength of the insulation system is rewarded by increased generator performance.

Finally, it is necessary to apply an intense axial preload (compressive force) to the laminated stack to increase the effective modulus of elasticity of the rotor. This is required to match rotor natural frequency constraints to the maximum tip speed permitted by mechanical stress limitations.

The Engineering Prototype Compulsator

An engineering prototype compulsator was designed and fabricated under contract to Lawrence Livermore National Laboratory (LLNL) to demonstrate the technical feasibility of driving xenon flashlamps using an electromechanical device directly (e.g., without an intermediate inductive energy store).[2] A cutaway drawing of the prototype machine is shown in Figure 2.

1. Eddy current losses in the solid steel pole faces reduce maximum inductance and increase effective resistance to reduce generator performance. (reduced amplitude, wider pulse width)
2. CEM-UT and LLNL impedance calculation codes and circuit simulation codes matched experimental waveforms provided that the position dependent pole face eddy current loss is included in the circuit model.
3. The Hexcel F-155/1581 pre-impregnated epoxy insulation system successfully transmitted the discharge forces during both normal and fault conditions.
4. The compliant stator mounting system (torque frame) operated as designed to limit the force transmitted to the foundation.
5. The 12x7x30 AWG Litz wire was subject to mechanical failure during fabrication and is prone to

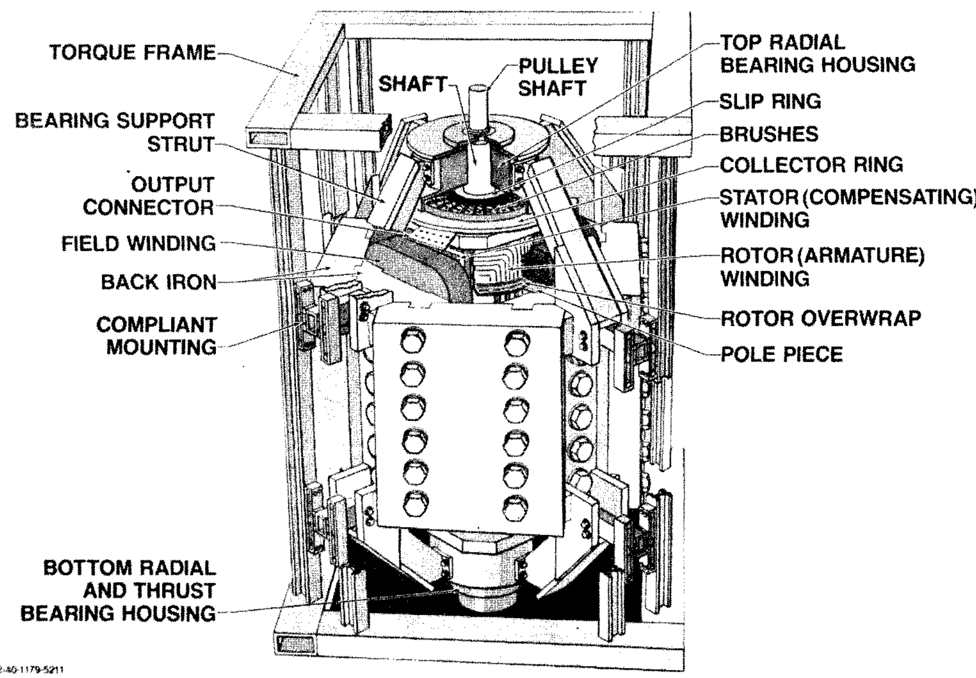

Fig. 2. Engineering Prototype Compulsator

The prototype was designed to deliver 200 kilojoules to a flashlamp load consisting of sixteen 15mm x 20mm x 112cm long xenon flashtubes connected in parallel with inductors provided in series with each lamp to help current balance.

The machine was successfully discharged at low speeds starting at 2400 rpm in 600 rpm increments. The device delivered 135 kilojoules to the flashlamp load with a 1.3 msec pulse width (full width half max), which was about twice the desired energy delivery time. Peak current exceeded 30 kA. Oscillograph traces of lamp voltage and lamp current are shown in Figure 3.[3] The prototype was run successfully at the maximum speed of 5400 rpm (unexcited, no load), but failed by internal terminal fault under open circuit conditions at full excitation (6.5 kV) just prior to discharge.

Based on the experimental results, computer circuit simulation, and a thorough inspection of the machine, we reached the following conclusions:

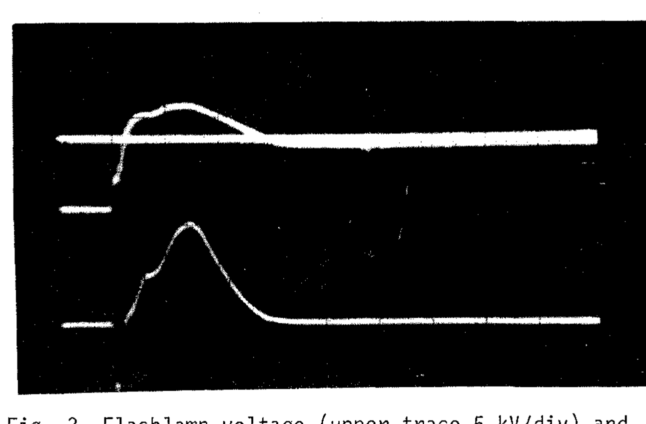

Fig. 3. Flashlamp voltage (upper trace 5 kV/div) and flashlamp load current (lower trace 16 kA/div) versus time (1 msec/div) December 20, 1979

development of hot spots (thermal runaway) along the rolled edges of the conductor.

6. The dielectric strength of the armature winding insulation in the vicinity of the end terminations was inadequate.

CY-80 Program Goals and Tasks

Although the engineering prototype machine did demonstrate the ability to drive flashlamps at significant power levels (120 megawatts), it failed to generate the desired pulse width due to reduced flux compression action. The measured inductance variation or compression ratio was between 6.5:1 and 10:1 compared to our original prediction of 40:1. The energy delivery was reduced from 200 kilojoules to less than 150 kilojoules due to eddy current resistance losses. Both problems were attributable to pole face eddy currents. A potential solution to this problem would have been to laminate the backiron and poles, or perhaps only the poles. This idea was dismissed because of cost and schedule constraints. Therefore, the following goals and tasks were proposed:

1. Increase delivered energy to 200 kilojoules by installing copper shield between compensating winding and solid steel pole faces.
2. Mock up shield and windings full scale to verify impedance calculations.
3. Improve the mechanical and electrical integrity of armature windings to reduce probability of an internal fault.
4. Verify enhanced inductance variation of fully laminated rotor and stator design. Fabricate 20 cm active rotary flux compressor for static impedance measurements.

Engineering Prototype Rebuild

The Copper Shield - Active vs. Passive Compensation

The solid poles of the prototype compulsator create a conducting boundary condition at the stator bore which limits inductance variation and increases resistive losses. These eddy current losses can be reduced by terminating the magnetic field in a higher conductivity non-ferromagnetic shield placed radially between the compensating winding and poles. However, doing so reduces the inductance variation even further --to the point that there is no significant reduction in pulse width due to flux compression.

After completing the full scale mock winding tests to verify that code impedances matched experimental inductance and resistance measurements, a series of circuit simulation computer runs were made to evaluate rewinding the prototype as a passively compensated, rather than an actively compensated machine.

In the passive configuration, a cylindrical copper shell is bonded in the stator bore in lieu of the serpentine compensating winding and thin copper shield. The copper shell is used as the current return path and is connected in series with the armature winding. The resistance of the shell is negligible compared to the serpentine winding, and eddy current losses are less because the magnitude of the terminated magnetic field at the inner radius of the copper shield is reduced.

A comparison of predicted prototype parameters for active and passive compensation are listed in Table I.

Based on the comparisons given in Table I, CEM-UT proposed to rebuild the prototype with passive compensation. For a machine having <u>solid</u> poles, passive compensation appears to be superior, although discharge times are still on the order of 1.1 to 1.3 msec.

TABLE I
Active vs. Passive Compensation (Predicted)
Engineering Prototype Rebuild with Shield

Parameter	Active	Passive
Number of poles	4	4
Polar moment of inertia ($J\text{-}sec^2$)	22	22
Maximum speed (rpm)	5400	5400
Peak voltage (kV)	6.10	6.45
Minimum inductance @ 200 Hz (μH)	24.6	23.0
Maximum inductance @ 200 Hz (μH)	74.6	23.0
Initial mechanical position (rad)	-0.93 to -0.57	-0.69 to -0.15
Mechanical angle L_{min} to V_{max} (rad)	0.24	0
Armature resistance @ 20°C (mΩ)	17.1	17.1
Compensating resistance @ 20°C (mΩ)	17.1	——
Maximum eddy current resistance (mΩ)(at 200 Hz)	68.8	8.9
Initial firing angle (rad)	-0.57	-0.15
Peak generator current (kA)	40.5	50.5
Peak terminal voltage (kV)	5.0	5.8
Peak output power (MW)	200	280
Total delivered energy (kJ)	212	215
Load energy (kJ)	200	200
Generator current halfwidth (msec)	1.3	1.1

Impedance Measurements

Upon completion of the rebuild, the internal impedance of the engineering prototype was measured versus frequency using a Hewlett Packard 5420A digital signal analyzer, oscillator, and power amplifier. Measured values of inductance and resistance are plotted versus frequency in Figures 4 and 5, respectively. Predicted values are also plotted for comparison.

Armature Conductor Redesign

The original armature winding was constructed using 12x7x30 AWG type 8 Litz wire wound ten in hand. For our purposes we found the 30 gauge filaments to be fragile and subject to mechanical damage during winding We therefore chose to rewind the armature with a more robust 14x24 AWG Litz wire. The larger filament conductor has higher open circuit eddy current losses, but this was acceptable since the applied field was to be pulsed for only 5 seconds, compared to the original design period of 60 seconds. The 14x24 AWG conductors were then wound twelve in hand in the same space, resulting in a 20 percent reduction in dc winding resistance.

Hi-Pot Testing

The end terminations of the prototype compulsator were redesigned to improve the basic electrical strength of the armature winding. A full scale mock-up

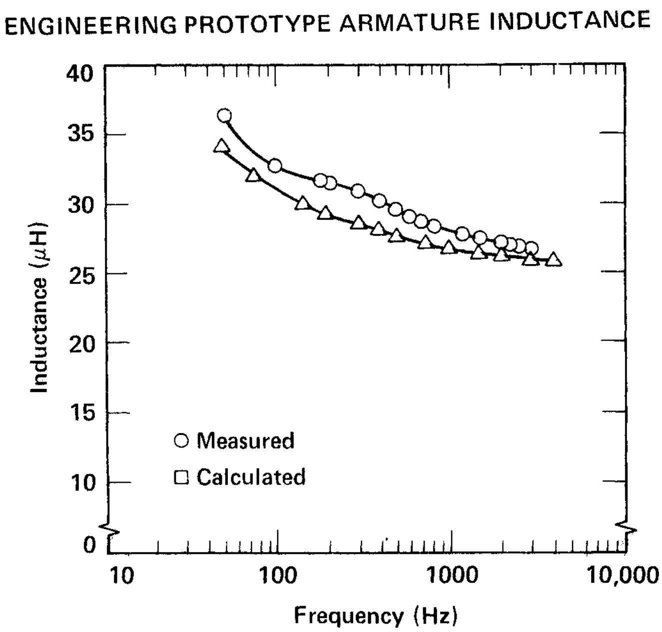

Fig. 4. Shielded Prototype Armature Circuit Inductance

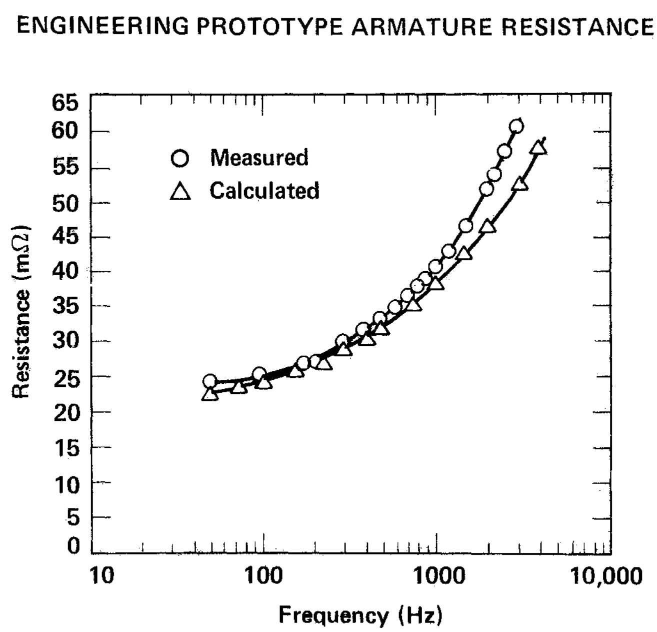

Fig. 5. Shielded Prototype Armature Circuit Resistance

of the new design was fabricated and successfully hi-pot tested at 15 kV dc. Upon completion of the rotor assembly, the armature winding was successfully hi-pot tested at 10 kV dc. It was decided to test the winding at 15 kV after lower speed, lower voltage tests were completed at 3600 rpm, but before testing at 4800 rpm and 5400 rpm. The tests at 10 kV indicated that the basic dielectric strength of the armature ground plane insulation was sound. Because the armature conductors were silver soldered into the slip rings prior to curing the fiberglass insulation, it was not possible to measure turn-to-turn insulation strength.

Pre-Impregnated Fiberglass Insulation System

A high mechanical shear strength pre-impregnated fiberglass insulation system was used for both the ground plane (Hexcel F-155/1581) and turn-to-turn (Hexcel F-155/120) insulation. This material was selected based on its mechanical properties, suitability to the serpentine winding fabrication, and available winding facilities.

The problem that we have experienced with the pre-impregnated insulation system is the inability to achieve a void free structure--primarily in the interior of an individual Litz wire. A Type 8 Litz wire is a spiral flattened tube of stranded and transposed filaments. The original plan called for wrapping the Litz wire around a strip of pre-preg tape. However, this was not practical on existing manufacturer equipment, and it was therefore a much more difficult task to fill the interior of the wires with epoxy.

Turn-to-Turn Failure Under Open Circuit

The rebuild of the engineering prototype was completed in September, 1980. Mechanical spin tests and open circuit voltage tests were initiated in October. Initial open circuit voltage tests made at 500, 1,000, and 2,400 rpm yielded identical values of 1.32 volts per rpm. During the fourth open circuit voltage test at 2,500 rpm, an abnormal deceleration and vibration of the rotor occurred (Test Run No. 28). Voltage measurements indicated that an internal turn-to-turn insulation failure occurred, and open circuit voltage was reduced to 1.12 volts per rpm. Current monitors indicated that no current flowed external to the rotor. Measured armature resistance after the run indicated that the armature winding had been damaged. Visual inspection of the rotor verified winding damage. The fault appeared to have occurred at a position near an end turn where wires had popped radially out of position during winding and had to be reworked.

The serpentine winding has both advantages and disadvantages. There are no end connections or joints in the conductors except at the connections to the slip rings. However, once the winding begins, the entire conductor is exposed to risk. If one section of the winding is damaged or fails to maintain position during fabrication, the entire conductor is scrapped. After reviewing the winding techniques used in the engineering prototype, we reached the following conclusions:

1. The armature should be wound with the rotor axis vertical rather than horizontal to avoid conductors drooping due to gravity.
2. Using extra epoxy to provide excess resin forms a lubricating fluid that enhances relative motion between conductors. Therefore, any additional epoxy should be applied only after the winding is complete.
3. Once conductors have moved, it is difficult to return them to the original position because of the tackiness of the pre-preg tape.

The Active Rotary Flux Compressor

In accordance with our goal to demonstrate the advantages of laminating both the rotor and stator to obtain non-conducting ferromagnetic boundary conditions a parallel task was proposed for CY 1980. A small scale (20 cm diameter rotor) active rotary flux compres sor was fabricated. The primary purpose of the device was to verify impedance calculations by comparing predicted values with static measurements.

An active rotary flux compressor (ARFC) is essentially a compulsator with the field winding removed. A schematic cross-sectional diagram of an ARFC is shown in Figure 6. Since the field windings have been removed, the stator is fabricated in a cylindrical rather than salient pole design. An external power source (a capacitor bank) is used to charge the machine with startup current when the rotor is in the maximum induc-

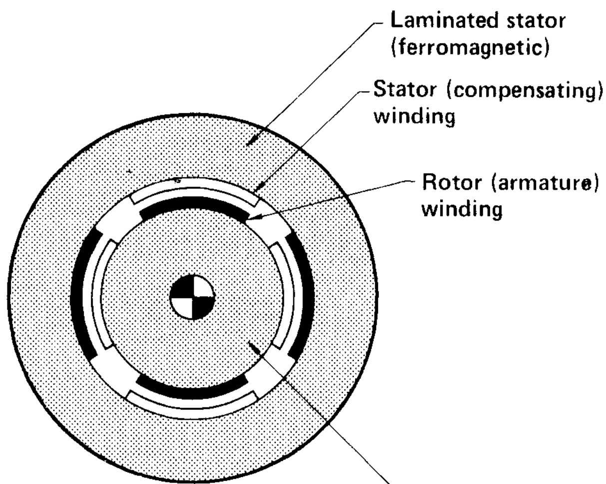

Figure 6

tance position. As the rotor position changes, the inductance decreases, driving the current to a value much greater (more than a factor of ten) than the value at startup. The primary advantage of the rotary flux compressor is the potential ability to repeat the discharge at least once per cycle in a burst of pulses before being recharged mechanically. A photo of the small scale ARFC is shown in Figure 7.

Additional information concerning the design and testing of this device is given in companion papers.[4,5] Oscillograph traces of terminal voltage and machine current under a staged short circuit test are shown in Figure 8. Note that the startup capacitor voltage is impressed across the machine terminals. At the voltage crossover, a diode connected in parallel with the capacitor becomes forward biased and short circuits the machine terminals.

The 20 cm ARFC parameters are listed in Table II.

TABLE II
ARFC Parameters

Rotor inertia	J-sec^2	0.39
Rotor speed	rpm	5400
Rated voltage	kV	3.0
Maximum inductance	mH	1.1
Minimum inductance	μH	24
Winding resistance	mΩ (dc)	42

Summary of Experimental Test Results--Millisecond Class Machine

The engineering prototype compulsator and the active rotary flux compressor have both served to further our understanding of the technical problems that must be overcome to develop an electromechanical pulse generator in the 500 μsec to 1.0 msec regime. The important conclusions that we have reached are summarized as follows:

Compulsators

1. To obtain significant flux compression and achieve pulsewidths less than one millisecond, it is necessary to provide non-conductive ferromagnetic boundaries on both the rotor and stator. This can be accomplished by fabricating the rotor and stator using stacks of thin electrical sheet steel laminations.

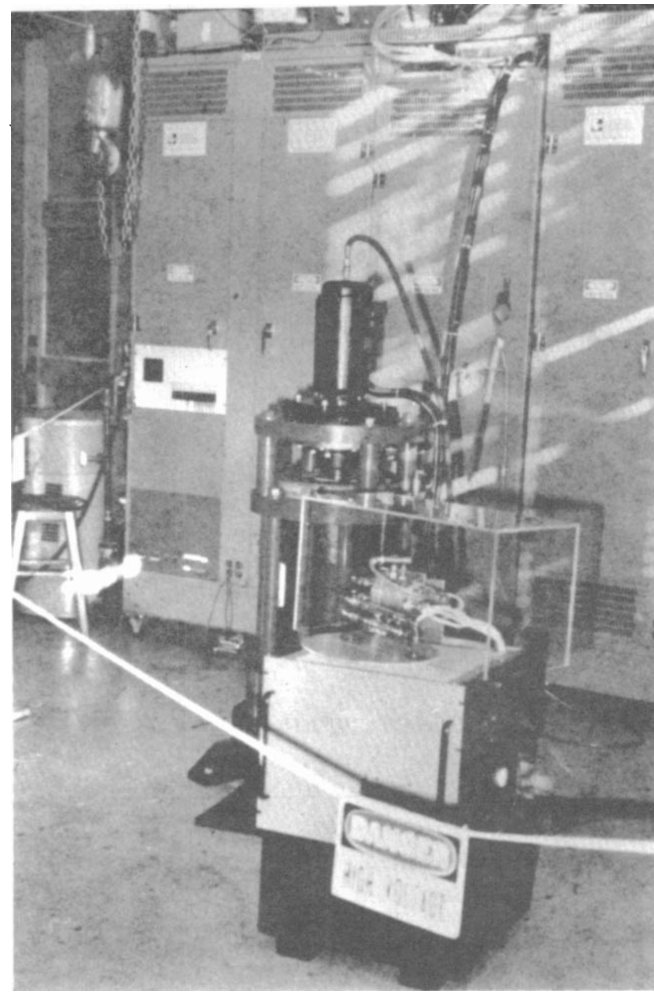

Fig. 7. Active Rotary Flux Compressor and Auxiliary Equipment

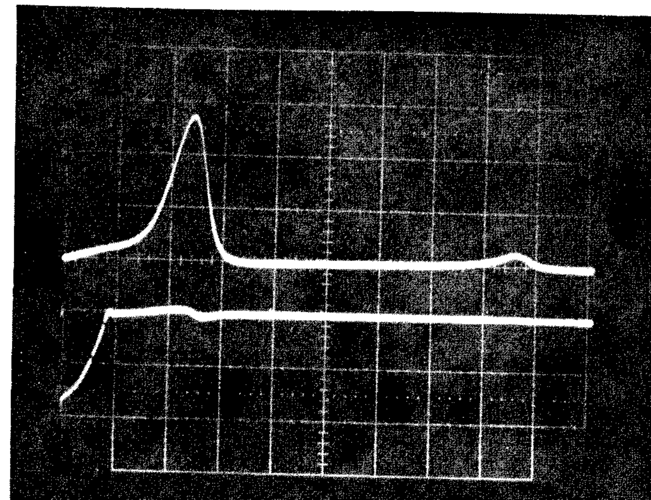

Fig. 8. ARFC Voltage and Current Waveforms vs. Time Staged Short Circuit Test (Top Trace-Current 10 kA/div; Bottom Trace-Terminal Voltage 1.77 kV/div; 1 msec/div) April, 1981.

2. The rotor laminations must be loaded in compression with an apparent compressive stress of approximately 30 MPa. A phosphate conversion coating is recommended for interlaminar insulation to avoid excessive mechanical creep.

3. Air gap windings are required to obtain minimum inductance and flux compression ratios necessary to provide the desired surface power densities.

4. Compensated pulsed alternators should be designed using filament sizes between No. 22 AWG and No.30 AWG. No. 26 AWG appears to be a good compromise between mechanical strength, mechanical stiffness, and open circuit eddy current losses.

5. Epoxy bonding of conductors to a smooth laminated steel surface is a feasible method for attaching air gap windings to rotor and stator structures.

6. Pre-impregnated fiberglass insulation systems do not provide the void free structure necessary to prevent relative motion of the windings under combined mechanical and electrical loading. Vacuum impregnation of the windings is recommended. A Dow Chemical DER 332 low viscosity epoxy system is suggested for use in vacuum impregnated windings.

7. Solid steel pole construction is feasible for discharge times of one millisecond or greater provided that a copper shield is used to reduce the magnitude of pole face eddy current losses. Passive compensation is recommended for solid pole designs.

8. CEM-UT and LLNL space harmonic magnetic field distribution codes accurately predict armature circuit resistance and inductance for solid pole machines having copper shields.

9. CEM-UT and LLNL circuit simulation codes accurately predict solid pole compulsator performance into non-linear flashlamp loads.

10. Eddy currents induced in the backiron, poles, and copper shield support the applied magnetic field in the event of local saturation of the rotor. Since the copper shield protects the field winding from transient armature flux, the open circuit voltage may be used for transient discharges. Armature reaction is not significant for a single pulse from shielded machines.

11. Additional code development is required to determine the performance of laminated stator compulsators. When the field coil is closely coupled to the armature, the field winding acts like a shorted turn and reduces inductance variation. If the field current is clamped to a constant value, severe transient voltages are induced in the field circuit. Magnetic saturation (armature reaction) must be considered in a fully laminated design. The mutual inductances between armature, field, and compensating windings must be determined as functions of both current and mechanical position. At present, this requires finite element method flux mapping methods which are not suited to optimization studies.

Active Rotary Flux Compressors

1. CEM-UT and LLNL space harmonic magnetic field codes accurately predict unsaturated ARFC inductance variation. Circuit simulation codes accurately predict flux compressor performance for unsaturated cases. The present magnetic saturation model is conservative, as 20 cm ARFC tests indicate that the actual effect of saturation (reduced current, increased pulsewidth) is less severe than predicted.

2. If larger rotary flux compressors are to be built at the same electrical frequency, it will be necessary to increase the conductor filament size to maintain packing factor. The limit in size may be determined by proximity effect--when the increase in ac to dc resistance ratio exceeds the reduction in dc resistance due to improved packing factor. It is anticipated that Roebel bar construction using 1.5mm square conductors will be utilized.

3. Although the 20 cm ARFC winding did not fail under short circuit discharge tests at rated voltage, it is recommended that the pre-impregnated insulation system be replaced with a vacuum impregnated dry glass tape. The surface speed of the 20 cm ARFC at 5400 rpm was half the surface speed of the engineering prototype machine.

4. Although an external startup capacitor is required the active rotary flux compressor does have some advantage in that an opening switch is not required. As can be seen in Figure 8, the magnitude of the secondary pulse is much smaller than the initial pulse.

Design of 100 Microsecond Machines

A primary incentive for developing faster machines is the need to charge large energy transfer capacitors, such as extremely high purity water capacitors at levels greater than one megajoule. CEM-UT has participated in several design studies aimed at charging capacitors directly or through a voltage step up pulse transformer.[6,7,8]

The approach to date has been to extrapolate ferromagnetic drum type rotary flux compressors or compulsators from the millisecond range to the 100 microsecond range by increasing the number of poles and increasing the rotational speed from say 150 m/sec to 200 m/sec (this requires a decrease in rotor l/D ratio) In addition, it has been necessary to decrease the size of the units to increase mechanical angular velocity while maintaining constant tip speed.

If one considers only the fundamental variation of inductance with angular position (neglect higher harmonics), the effective armature inductance is given by

$$L(\theta_m) = L_{min} + \Delta L \left[1-\cos\left(\frac{N_p\theta_m}{2}\right)\right] \text{ H} \qquad (1)$$

where N_p is the number of poles, and θ_m is the mechanical position of the rotor. In an ideal lossless system the flux linkage is constant. If L_o and i_o are initial values of inductance and current, respectively, then the short circuit current is given by

$$i(\theta_m) = L_o i_o / L(\theta_m) \qquad (2)$$

For constant mechanical angular velocity ω_m, it can be shown that the pulsewidth (full width half max) $\Delta t_{1/2}$ is given by Equation 3

$$\Delta t_{1/2} = \frac{4}{N_p\omega_m}\left\{\cos^{-1}\left[CR\text{-}3/CR\text{-}1\right]\right\} \qquad (3)$$

where the compression ratio CR is the ratio of maximum to minimum inductance. The compression ratio is a function of rotor diameter, conductor thickness, voltage rating, and number of poles. Rotor diameter is plotted as a function of short circuit pulsewidth for several numbers of poles in Figures 9 and 10. At higher voltages using thicker (more efficient) conductors, the minimum short circuit pulse width is on the order of 500 μsec. Faster times are achievable

(<100 μsec) if the rated voltage and conductor thickness are reduced.

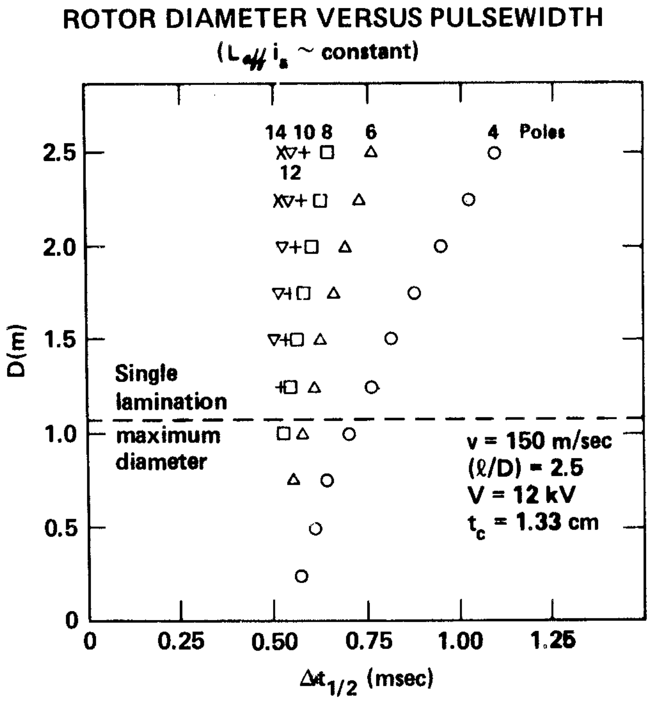

Fig. 9. Rotor Diameter vs. Ideal Short Circuit Pulsewidth V = 12 kV

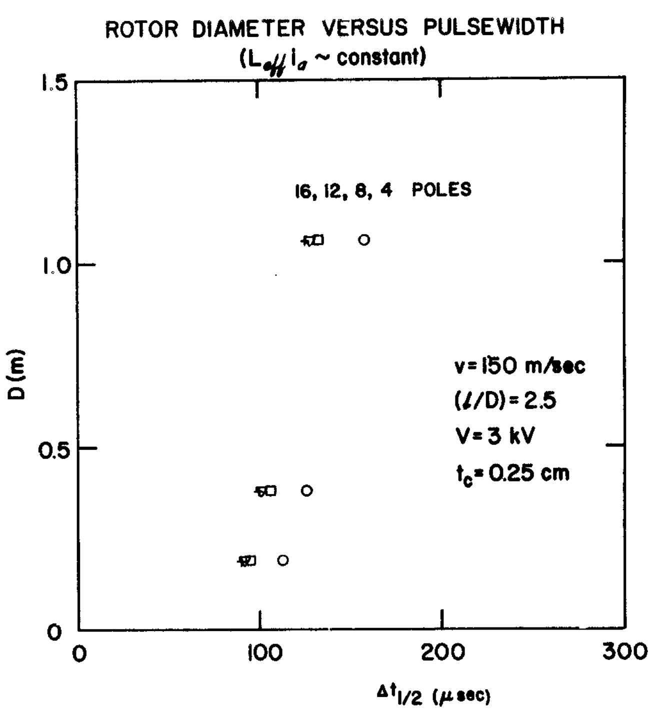

Fig. 10. Rotor Diameter vs. Ideal Short Circuit Pulsewidth V = 3 kV

Actual short circuit pulsewidths are greater due to the internal resistance of the devices. One can also see that after a point, increasing the number of poles does not reduce pulsewidth because of the reduction in flux compression ratio.

The effects of internal impedance and flux compression ratio on energy gain for capacitive loads are illustrated in Figure 11. The winding resistance reduces energy gain by a factor of two. However, stray eddy current losses associated with axial flux generated by uncompensated end turns is a much more severe problem at high frequencies.

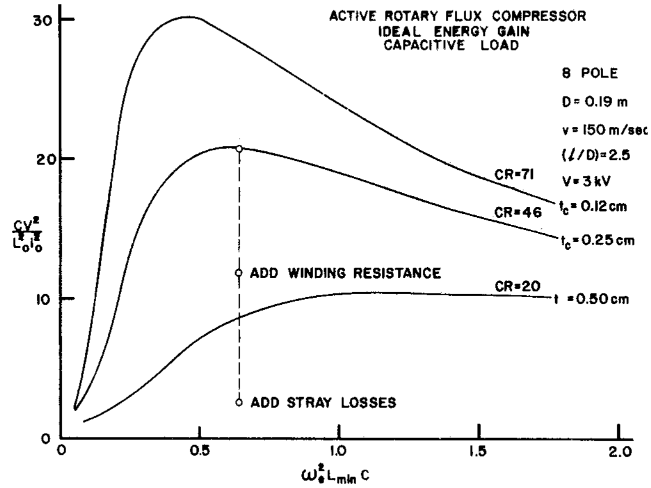

Fig. 11. Ideal Energy Gain ARFC Into Capacitive Load

The Brushless Rotary Flux Compressor (BRFC)

An alternative approach has been suggested using a fluted rotor manufactured from solid aluminum or steel.[6,7] The device is a brushless rotary flux compressor. A simplified schematic diagram is shown in Figure 12.

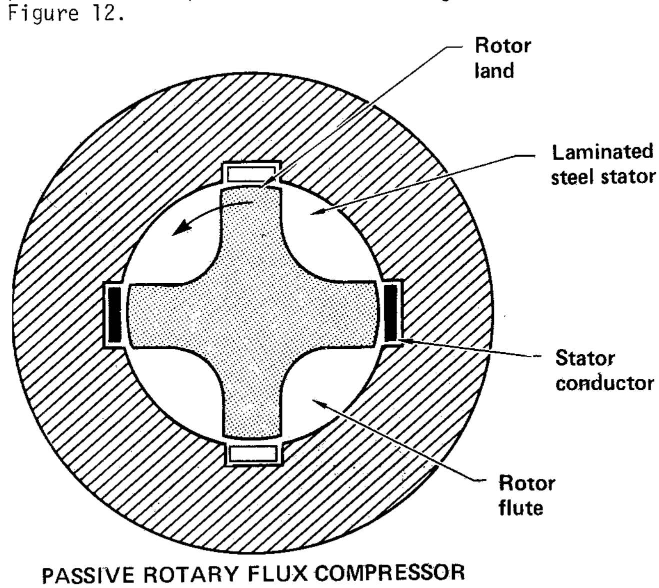

Fig. 12. Brushless Rotary Flux Compressor

The BRFC is analagous to the passively compensated pulsed alternator. However, the introduction of the rotor flutes yields a variable inductance. The advantage of this topology is increased surface speed (approaching 300 m/sec) and a natural frequency doubling effect. A four pole stator winding yields an 8 pole inductance variation with a fluted rotor having four raised lands. The disadvantage of this topology is that the conductive rotor boundary condition yields a relatively small flux compression ratio (less than 10) compared to variations of 40 or more for the active rotary flux compressor. In short, the BRFC yields faster pulses, but has smaller energy gain than an ARFC

Future 100 Microsecond Machine Designs

Theoretically, 100 microsecond pulses can be obtained by extrapolating the ferromagnetic drum configuration to smaller sizes, lower voltages, and faster speeds. A program is now underway to optimize the design of a rotary flux compressor to charge a capacitor in 100 microseconds. However, the delivered energy per pulse must decrease with pulsewidth unless an order of magnitude improvement in surface power density is realized.

One limit to surface power density is the maximum mechanical shear strength of the insulation system. This limit can be increased substantially if the conductors are imbedded in a fiberglass-epoxy matrix to form a thin cylinder or thin disk that is not attached to the ferromagnetic boundary. Counterrotating armature and compensating windings can be realized in either drum or disk configurations. In these designs the majority of the inertia is in the conductors themselves, where electromagnetic body forces are generated. Therefore, the insulation system is not required to transmit deceleration forces in shear. Another advantage of counterrotating designs is that the relative velocity between the armature winding and compensating winding is doubled, reducing pulsewidth by a factor of two.

The major disadvantages to the counterrotating designs are mechanical. The counterrotating drum is subject to mechanical vibration and requires improved radial bearing design. The counterrotating thin disk configuration is subject to bending stresses in the disks due to the large repulsive forces between coils and requires improvements in thrust bearing design. These issues must be taken to task before suggesting that the counterrotating configurations will provide the necessary improvement in peak power capability.

Conclusions

The Center for Electromechanics of the University of Texas at Austin has proposed that the compensated pulsed alternator, and the rotary flux compressor be considered as candidates for future pulse power sources for pulse times of one millisecond or less. At the present time experimental results and code development indicate that an active rotary flux compressor can be designed to efficiently drive flashlamps in 500 μsec to 750 μsec. Passively compensated solid pole compulsators are effective flashlamp drivers for times on the order of one millisecond. Additional code development is required to determine the feasibility of using fully laminated compulsators for sub-millisecond pulses.

While the ferromagnetic rotor drum configuration can be shown to produce 100 microsecond pulses, advances in rotor technology will be required to maintain the same level of delivered energy per pulse as the 500 μsec - 1 msec machines.

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